HYDROGEOLOGY OF THE SURFICIAL AQUIFER IN THE VICINITY OF A FORMER LANDFILL, NAVAL SUBMARINE BASE KINGS BAY, CAMDEN COUNTY, GEORGIA

by David C. Leeth

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 98-4246

Prepared in cooperation with

U.S. DEPARTMENT OF THE NAVY
SOUTHERN DIVISION NAVAL FACILITIES ENGINEERING COMMAND

Atlanta, Georgia

1999

U.S. DEPARTMENT OF THE INTERIOR

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VERTICAL DATUM

Sea Level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called “Sea Level Datum of 1929.”

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ABSTRACT

Neogene and Quaternary sediments constitute the surficial aquifer beneath the study area; in descending order from youngest to oldest these include—the Quaternary undifferentiated surficial sand and Satilla Formation; the Pliocene(?) Cypresshead Formation; and the middle Miocene Coosawhatchie Formation. Beneath the surficial aquifer, the upper Brunswick aquifer consists of part of the lower Miocene Marks Head Formation.

The surficial aquifer is divided into three water-bearing zones on the basis of lithologic and geophysical properties of sediments, hydraulic-head differences between zones, and differences in ground-water chemistry. The shallowest zone—the water-table zone—consists of medium to fine sand and clayey sand and is present from land surface to a depth of about 77 feet. Below the water-table zone, the confined upper water-bearing zone consists of medium to very coarse sand and is present from a depth of about 110 to 132 feet. Beneath the upper water-bearing zone, the confined lower water-bearing zone consists of coarse sand and very fine gravel and is present from a depth of about 195 to 237 feet. Hydraulic separation is suggested by differences in water chemistry between the water-table zone and upper water-bearing zone. The sodium chloride type water in the water-table zone differs from the calcium bicarbonate type water in the upper water-bearing zone. Hydraulic separation also is indicated by hydraulic head differences of more than 6.5 feet between the water-table zone and the upper water-bearing zone.

Continuous and synoptic water-level measurements in the water-table zone, from October 1995 to April 1997, indicate the presence of a water-table high beneath and adjacent to the former landfill—the surface of which varies about 5 feet with time because of recharge and discharge. Water-level data from clustered wells also suggest that restriction of vertical ground-water flow begins to occur at an altitude of about 5 to 10 feet below sea level (35 to 40 feet below land surface) in the water-table zone because of the increasing clay content of the Cypresshead Formation.

INTRODUCTION

Naval Submarine Base Kings Bay, a U.S. Department of the Navy facility in north-central Camden County, Georgia, lies east of Kings Bay about 4 miles north of St Marys, Georgia. Several sites on the base were identified under the Resource Conservation and Recovery Act for investigation.

In January 1992, volatile organic contaminants were detected in ground water at the former Camden County, Georgia landfill during a Resource Conservation and Recovery Act facility investigation (RFI) at concentrations exceeding U.S. Environmental Protection Agency (USEPA) water-quality standards (U.S. Environmental Protection Agency, 1990a,b, 1996). The former landfill is located on the U.S. Department of the Navy (Navy), Naval Submarine Base (NSB) Kings Bay. The landfill, referred to as Site 11 by the Navy and in this report, was operated as a municipal landfill and reportedly did not receive hazardous wastes. Data from the facility investigation were insufficient to place the local hydrogeologic system of Site 11 within a more regional hydrogeologic context—a primary focus of this report.

Successful remediation of contaminated ground water is predicated on understanding the hydrogeologic framework that controls the movement of contaminated ground water in the subsurface. An understanding of the local and regional hydrogeologic framework of the surficial aquifer in the vicinity of the former landfill is needed to manage and direct current and future remedial measures. In response to this need, the U.S. Geological Survey (USGS), in cooperation with the Navy, entered into a cooperative agreement to relate the geology, hydrology, and water quality of the local ground-water flow system to that of the regional ground-water flow system.

Purpose and Scope

This report describes and relates the hydrogeology and stratigraphy at Site 11 to the regional hydrogeology and stratigraphy described by Clarke and others (1990). Data collected during this investigation can be used to assess the movement and quality of ground water in the vicinity of the NSB. This report describes:

- the relation of the lithology, stratigraphy, and structure of the surficial aquifer in the vicinity of Site 11 to the regional hydrogeologic framework described by Clarke and others (1990);
- long-term water-level fluctuations and the configuration of the water table at site 11;
- the definition of Site 11 hydrogeology by evaluating differentation between selected water-bearing zones;
- hydraulic properties of selected water-bearing zones;
- Darcian ground-water-flow velocities in the water-table zone; and
- the general water quality of the surficial aquifer.

The scope of the investigation includes collection of a continuous core to a depth of 310 feet (ft) and construction of nine observation wells; examination of drill core and geophysical logs; water-level measurements; sampling of selected wells for chemical analysis of water, and aquifer tests in selected wells. The investigation was begun in October 1995 and completed in April 1998. Hydrogeologic units discussed herein are present from land surface to a depth of about 310 ft.

Description of the Study Area

A general description of the physiography and climate of the NSB Kings Bay vicinity is included to aid readers in comparing site-specific data from this report with data from other locations. Also, climatic data can be used for water-budget or ground-water modeling efforts.

NSB Kings Bay lies in southeastern Camden County, Ga., and is bounded on the north by the Crooked River State Park, on the east by the Crooked River and Cumberland Sound, to the south by the corporate boundary of St Marys, Ga. (fig. 1), and to the west by Georgia State Highway 40 (spur) (fig. 2). NSB Kings Bay lies in the Barrier Island Sequence District, Sea Island Section of the Coastal Plain Province of Georgia (Clark and Zisa, 1976). Topographic relief across NSB Kings Bay is low, with the minimum altitude of sea level to the east and a maximum altitude of about 34 ft to the west. Relief is largely a consequence of relict shorelines that were formed during global sea level fall during Plio-Pleistocene time (Leve, 1966).

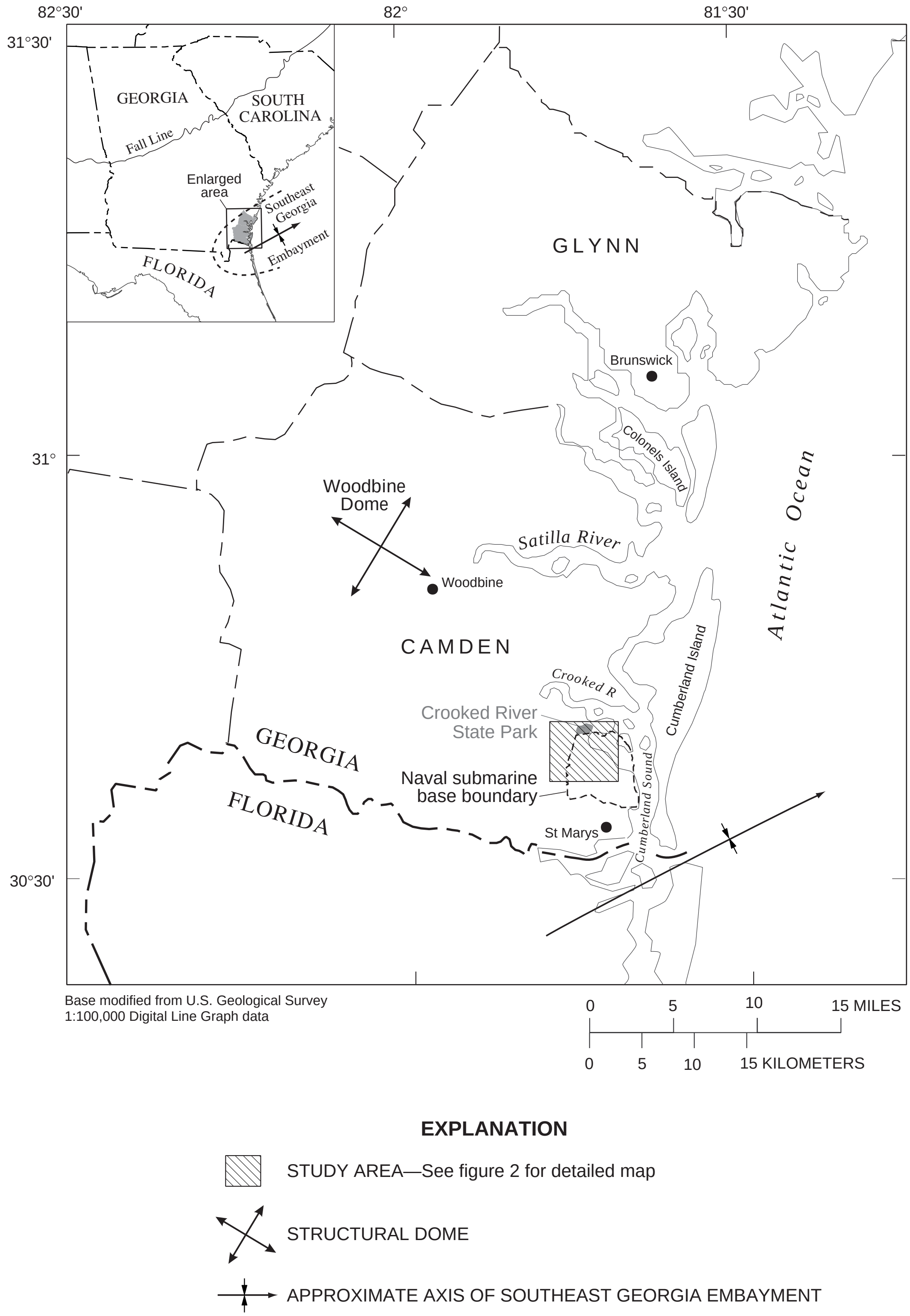


Figure 1. Location of study area, structural features, and Naval Submarine Base Kings Bay, Camden County, Georgia.

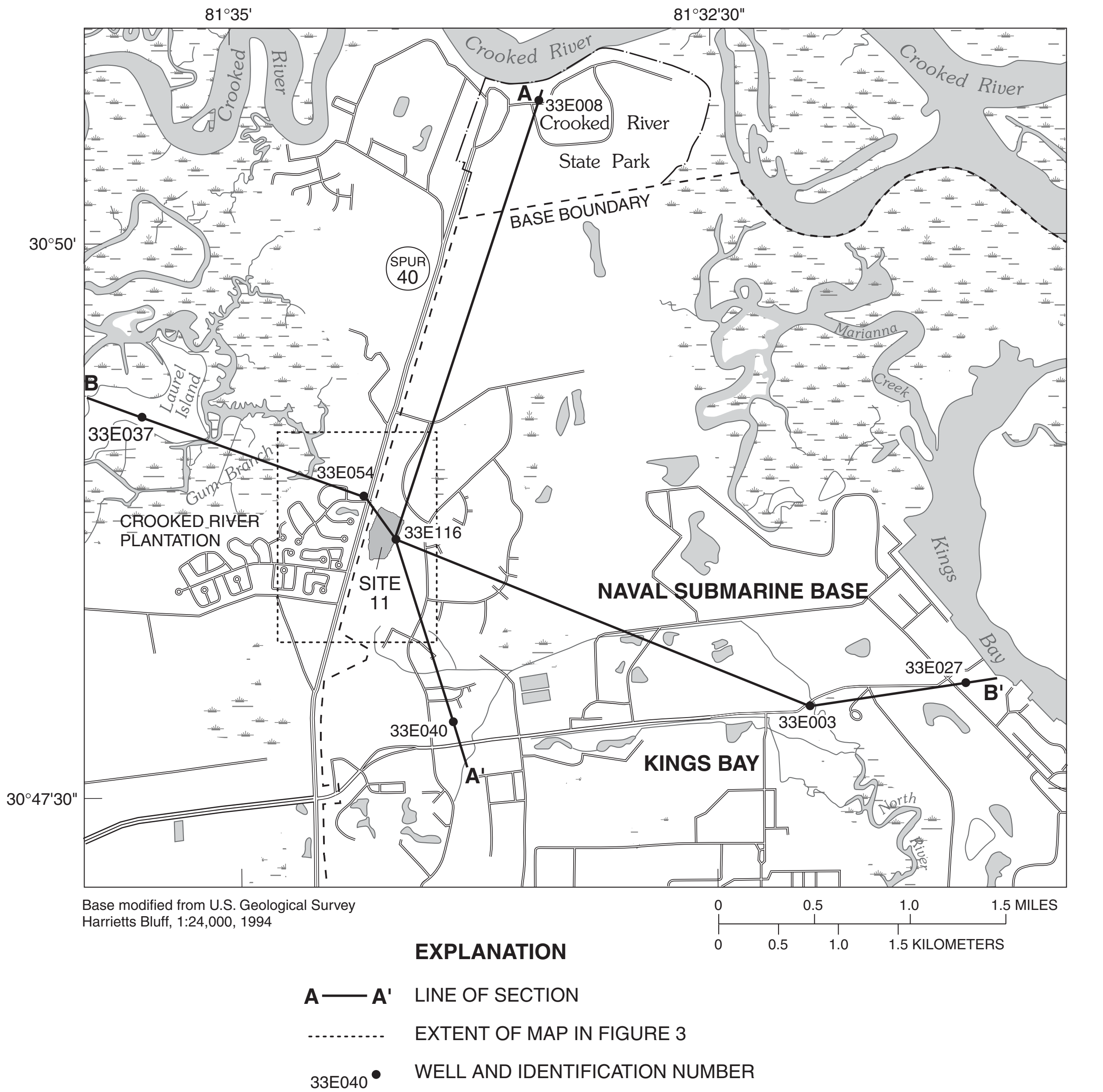
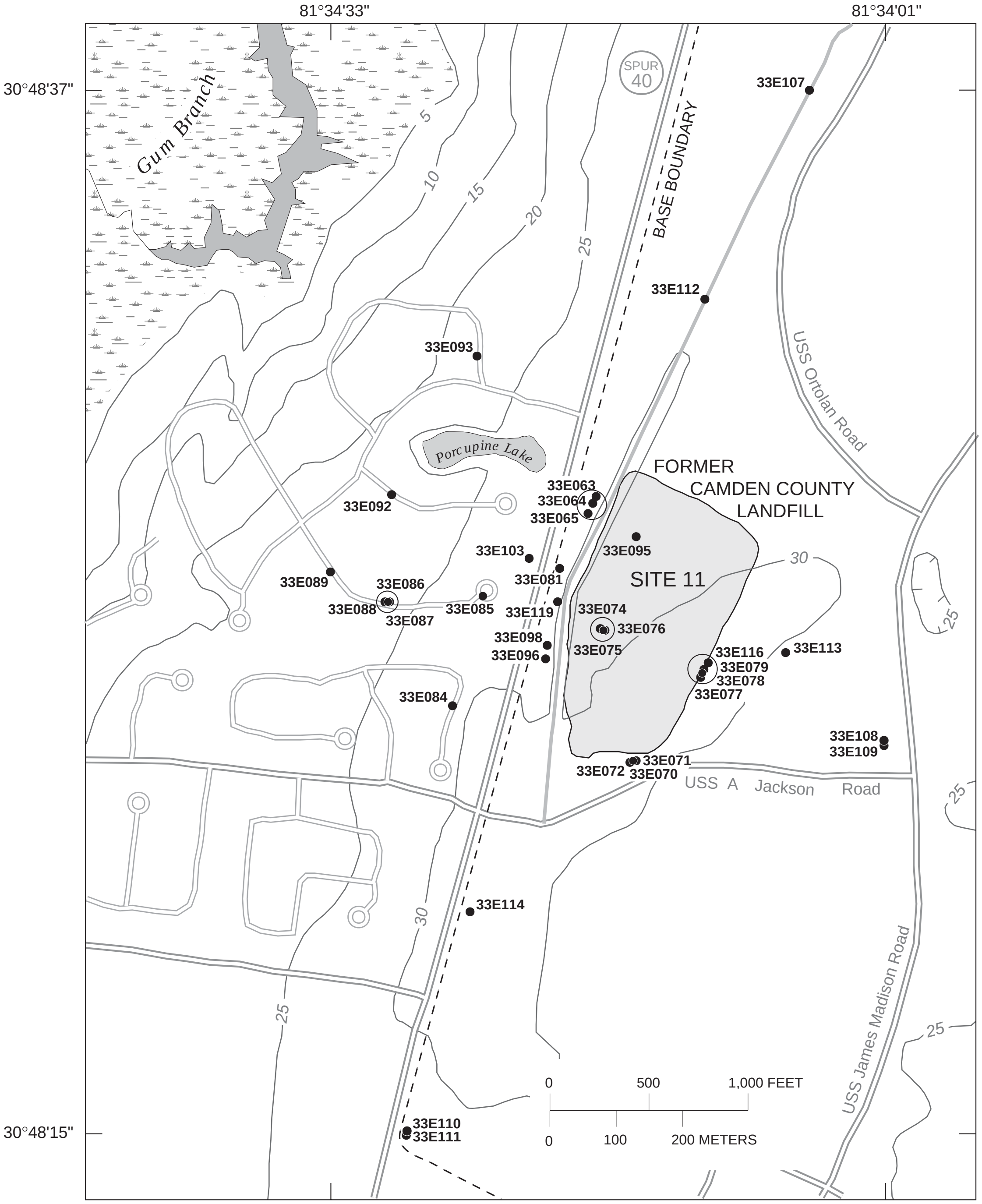


Figure 2. Extent of study area and Site 11, location of wells used to define the hydrogeology of the surficial aquifer, and lines of hydrogeologic sections (sections shown in figures 5 and 6), Naval Submarine Base Kings Bay, Camden County, Georgia.

Knowledge of the local physiography is important to understand the movement of ground water in a water-table aquifer. The study area for this investigation consists of about 12 square miles (mi^2) approximately centered around Site 11 (fig. 2). Site 11 is a former Camden County municipal landfill that encompassed about 35 acres while in operation (figs. 2 and 3). The landfill was covered with fine to medium sand mined from around the base (U.S. Department of the Navy, 1994). The landfill is located on a 34-ft-high ridge that trends northeast to southwest; this ridge is a geomorphic feature known as a marine terrace. The landfill lies within what Huddlestun (1988) termed the Pamlico terrace complex. Site 11 lies along the western border of the base, east of a housing subdivision known as Crooked River Plantation (fig. 2). The subdivision consists of approximately 600-single-family homes and is separated from NSB by a 50-foot right-of-way for Georgia State Highway 40 (spur).



Base modified from U.S. Geological Survey digital raster graphic, Harrietts Bluff, 1:24,000, 1994

EXPLANATION

— 30 — LAND-SURFACE CONTOUR—Shows altitude of land surface. Contour interval 5 feet. Datum is sea level

• 33E114 WELL AND IDENTIFICATION NUMBER

○ WELL CLUSTER

Figure 3. Wells used to define the hydrogeology of the water-table zone, Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia.

The movement of ground water primarily is a function of gravity. Thus, ground water—in the water table—moves from interstream areas toward streams or the coast. Because the landfill is located on a ridge, surface-water runoff flows in two directions. Runoff from the west side of the landfill is likely discharged into Gum Branch (fig. 2); runoff from the east side of the landfill flows into various drainage ditches, and is predominantly discharged into the North River (fig. 2).

The climate of southeastern Georgia is humid subtropical and is characterized by long, warm, relatively wet summers; and mild relatively dry winters. The mean-annual rainfall for Camden County ranges from 52 to 54 inches (St. Johns River Water Management District, 1977). About 60 percent of the annual rainfall occurs from June through September, ranging from about 6 to 8 inches per month. October through May are the dryer months when average rainfall ranges from 2 to 4 inches per month (Brown, 1984). Evapotranspiration in southern Camden County is about 30 to 40 inches per year, with about 60 percent occurring from April through September (Brown, 1984).

Methods of Investigation

The methods of investigation consisted of both indirect and direct measurement of various hydrologic and geologic properties, by test-well drilling, geophysical logging, aquifer testing, water-level measurements, rainfall measurements, and water-quality sampling. In addition, water quality and water levels were measured in previously drilled shallow wells. These data were used to differentiate the two deeper water bearing units at Site 11 from the water table (unconfined part) of the surficial aquifer as defined by Clarke and others (1990); to describe the water table of the aquifer; and to relate the hydrology of Site 11 to the regional hydrogeologic framework.

Borehole geophysical logs were used to correlate strata at the site and to relate local strata to the regional hydrogeologic framework. At well 33E116 (fig. 2), continuous core was collected from land surface to a depth of 310 ft. Lithologic and geophysical data from this corehole and from other test wells were used to evaluate both the local and regional hydrogeology. The uniform nature of electrical and natural gamma radiation characteristics of sediments underlying the area, is used to aid in correlating stratigraphic units and water-bearing zones. Also, geophysical logs were available in areas where little paleontologic or lithologic control exists. The work of Huddlestun (1988) was used as a basis for lithostratigraphic correlation near the site.

Results of aquifer tests were used to estimate aquifer properties such as hydraulic conductivity, transmissivity, and ground-water flow rates. Hydraulic properties of two of the water-bearing units at Site 11 were determined from two aquifer tests conducted during this study. Data from published and unpublished sources provided additional information on regional hydraulic properties of the aquifers.

Long-term continuous and synoptic water levels were measured in selected wells (table 1) at Site 11. Long-term continuous water levels measured in three wells were used to assess water-level fluctuations and trends in the unconfined part of the surficial aquifer. Discrete water-level measurements of selected monitor-well clusters—groups of wells, located in close proximity with progressively deeper well-screen elevations—were used to show hydraulic separation between the unconfined and confined parts of the surficial aquifer. Synoptic water-level measurements were used to construct water-table-surface maps for the unconfined part of the surficial aquifer; in addition, anisotropy in the unconfined part of the aquifer is shown using head measurements within that part of the aquifer.

As a part of this investigation, a geologic core was drilled to a depth of 310 ft and a core was taken from the corehole. The corehole then was backfilled with a cement and bentonite grout to a depth of 170.5 ft. After backfilling, the corehole was reamed to a diameter of 12 inches and a 6-inch diameter screened well (33E116, fig. 2) was completed to a depth of 170.5 ft. In addition, nine wells were installed in the unconfined part of the surficial aquifer—distal to Site 11—to measure water levels and sample water quality.

Water samples from eight wells were analyzed for dissolved concentrations of inorganic constituents. These chemical analyses were used to describe the general ground-water quality and to differentiate between two of the water-bearing units based on major ionic composition.

Land-surface altitudes of wells first must be determined to accurately construct water-table or potentiometric-surface maps. Land-surface altitudes at wells 33E008, 33E037, 33E054, and 34E001 were estimated using USGS 7 1/2-minute topographic maps. USGS personnel determined land-surface altitudes at the remaining wells using elevation benchmarks.

Table 1. Location and construction data for wells used in this study
[—, no data]

Well number	Well name	Latitude	Longitude	Altitude (feet)		
				Top of screen or open interval	Bottom of screen or open interval	Land surface
33E003	NSB refill station	30°47'51"	81°32'01"	-292.3	-460	9.7
33E008	Crooked River State Park	30°50'37"	81°33'23"	-247	-444	16
33E027	NSB TW-01	30°47'56"	81°31'11"	-555.48	-979.58	10.42
33E037	C. Drury	30°49'13"	81°35'31"	—	575	10
33E039	NSB observation well 01	30°47'49"	81°33'53"	-923.51	-423.51	26.49
33E040	NSB observation well 02	30°47'49"	81°33'53"	-533.51	-723.51	26.49
33E054	Rayland Co. 01	30°48'50"	81°34'20"	-353	-612	28
33E063	KBA-11-03A	30°48'44"	81°34'18"	26.34	16.34	28.64
33E064	KBA-11-03B	30°48'44"	81°34'19"	-7.70	-17.70	27.91
33E065	KBA-11-03C	30°48'44"	81°34'19"	-56.41	-66.41	28.16
33E070	KBA-11-08A	30°48'32"	81°34'16"	29.39	19.41	32.48
33E071	KBA-11-08B	30°48'32"	81°34'16"	1.58	-8.78	31.83
33E072	KBA-11-08C	30°48'32"	81°34'16"	-18.35	-28.01	31.74
33E074	KBA-11-10A	30°48'38"	81°34'17"	22.73	12.73	32.52
33E075	KBA-11-10B	30°48'38"	81°34'18"	-6.76	-16.76	32.45
33E076	KBA-11-10C	30°48'38"	81°34'17"	-43.81	-54.81	32.52
33E077	KBA-11-11A	30°48'36"	81°34'12"	5.86	-4.14	30.47
33E078	KBA-11-11B	30°48'36"	81°34'11"	-13.75	-23.75	30.39
33E079	KBA-11-11C	30°48'37"	81°34'11"	-37.79	-47.79	30.31
33E081	KBA-11-13A	30°48'41"	81°34'20"	-1.39	-11.39	29.15
33E084	KBA-11-15	30°48'35"	81°34'26"	-3.60	-13.60	25.81
33E085	KBA-11-16	30°48'41"	81°34'24"	-9.33	-19.33	26.00
33E086	KBA-11-17A	30°48'40"	81°34'29"	2.62	-7.38	23.00
33E087	KBA-11-17B	30°48'40"	81°34'29"	-12.48	-22.48	22.90
33E088	KBA-11-17C	30°48'40"	81°34'30"	-53.03	-63.03	22.87
33E089	KBA-11-18	30°48'41"	81°34'33"	-16.08	-26.08	20.34
33E092	KBA-11-20	30°48'45"	81°34'29"	-10.02	-20.02	20.47
33E093	KBA-11-21	30°48'51"	81°34'24"	-9.93	-19.93	20.94
33E095	KBA-11-22B	30°48'42"	81°34'15"	-9.56	-19.56	30.10
33E096	KBA-PS-01	30°48'37"	81°34'21"	-0.07	-5.07	30.15
33E098	KBA-PS-03	30°48'38"	81°34'21"	-0.05	-5.06	30.15
33E103	KBA-PD-08	30°48'42"	81°34'21"	-21.06	-26.06	26.28
33E107	USGS well 01B	30°48'37"	81°34'10"	-11.93	-21.93	27.57
33E108	USGS well 02A	30°48'32"	81°34'01"	-17.51	-7.51	27.01
33E109	USGS well 02B	30°48'32"	81°34'01"	-12.46	-22.46	27.04
33E110	USGS well 03A	30°48'15"	81°34'29"	20.34	10.34	29.84
33E111	USGS well 03B	30°48'15"	81°34'29"	-9.48	-19.48	30.02
33E112	USGS well 04	30°48'53"	81°34'11"	-12.80	-22.80	26.70
33E113	USGS well 06	30°48'37"	81°34'06"	-9.46	-19.46	30.04
33E114	USGS well 09	30°48'25"	81°34'25"	-7.49	-17.49	32.01
33E116	USGS core well	30°48'39"	81°34'10"	-69.86	-109.86	30.14
33E119	KBA-RW-06	30°48'39"	81°34'20"	2.66	-37.34	31.66
34E001	GGS TW-01	30°45'22"	81°28'13"	-523	-628	17

Previous Investigations

Recent investigations evaluating the hydrology and geology of the NSB Kings Bay are limited to remediation-derived reports by the Navy (U.S. Department of the Navy, 1993, 1994). Geologic and hydrogeologic data for the NSB are discussed in the initial environmental impact statement for the base (U.S. Army Corps of Engineers, Savannah District, 1977) and by a follow-on study specifically addressing the occurrence of the unconfined ground-water system (U.S. Army Corps of Engineers, Savannah District, 1978).

Brown (1984) evaluated the impact of development on availability and quality of ground water in eastern Nassau County, Fla., and southeastern Camden County, Ga. Saltwater intrusion and water quality in the Floridan aquifer system of northeastern Florida (including extreme southern Camden County, Ga.) were evaluated by Spechler (1994). Geologic and hydrologic controls of chloride contamination in aquifers at Brunswick, Ga., were described by Gregg and Zimmerman (1974). Soils and Materials Engineers, Inc., described the ground-water resources in Pliocene to Holocene deposits at Skidaway Island, Ga. (1986a), and in Miocene deposits at Colonel's Island, Ga. (1986b).

More areally extensive studies include a digital-model evaluation of the Floridan aquifer system and an extensive bibliography on the hydrology and geology of southeastern Georgia, and adjacent parts of Florida and South Carolina by Krause and Randolph (1989). Krause and others (1984) and Clarke and others (1990) described the geology and ground-water resources of the coastal Georgia area. A review and revision of the lithostratigraphy of the Georgia Coastal Plain is discussed by Huddlestun (1988). Herrick (1965) described the subsurface extent of Pliocene (?)-Pleistocene deposits in coastal Georgia.

Well-Numbering System

Each observation well used in this report is numbered according to a system based on the USGS index of topographic maps. Each 7 1/2-minute topographic quadrangle in Georgia has been given a number and letter designation beginning at the southwestern corner of the State. Numbers increase eastward and letters increase alphabetically northward. Quadrangles in the northern part of the area are designated by double letters. The letters "I," "II," "O," and "OO" are omitted. Wells inventoried in each quadrangle are numbered consecutively beginning with 1. Thus, the 8th well numbered on the 33E quadrangle is designated 33E008. All well locations in this report are on the USGS Harriet's Bluff 7 1/2-minute topographic quadrangle which is designated 33E in the well-numbering system outlined above. Information on well locations and construction specifications, and geologic and hydrologic data from this report may be found in Cressler (1998) or at the USGS, Atlanta, Ga. A summary of well identification (grid numbers), well name, location, and selected construction data for wells used in this report is given in table 1.

Acknowledgments

The cooperation and assistance of Mr. Anthony B. Robinson and Ms. Rhonda Bath, U.S. Department of the Navy, are gratefully acknowledged. Thanks also goes to Ms. Laura Harris and Mr. Kurt Sichelstiel, ABB-Environmental Services, who were forthright in sharing their data and knowledge.

HYDROGEOLOGY

The Floridan aquifer system is the primary source of water for all uses in coastal Georgia. Secondary sources of water include the upper and lower Brunswick aquifers (Clarke and others, 1990) and the surficial aquifer (Miller, 1986; Krause and Randolph, 1989; Clarke and others, 1990). Distribution of ground water is controlled, in part, by the presence and geometry of the aquifer/confining unit system of an area; these, in turn, are controlled by the lithology, stratigraphy, and structure of the regional and local geologic setting (Gorelick and others, 1993)—otherwise known as the hydrogeology or the hydrogeologic framework. Discussion of the local hydrogeologic framework is of limited use outside the context of the regional framework. In this report, the surficial aquifer of Clarke and others (1990) is divided into three water-bearing units and placed within the context of the documented regional hydrogeologic framework.

Regional Geologic Setting

Camden County, Ga., is underlain by about 5,500 ft of Cretaceous to Holocene strata (Wait and Davis, 1986). These strata consist of unconsolidated to semi-consolidated clastic Coastal Plain sediments, and semi-consolidated and consolidated carbonate Coastal Plain sediments. The strata strike southwest to northeast, and dip and thicken to the southeast. The strata unconformably overlie Proterozoic felsic volcanic rocks in northern Camden County, and Paleozoic metamorphic rocks in southern Camden County (Chowns and Williams, 1983). NSB Kings Bay lies southwest of a structural dome that is centered near Woodbine, Ga., on the northern flank of the Southeast Georgia Embayment (fig. 1).

Geologic Units

The emphasis of this report is on hydrogeologic units in lower Miocene to Holocene strata—units in older sediments are not discussed. Miocene sediments consist of interbedded sand, clay, and limestone. Pliocene and Quaternary sediments are typically discontinuous sand, clay, and shell beds. The generalized correlation chart showing the lithologic and hydrogeologic units in the vicinity of Site 11 (fig. 4) is based on the corehole drilled at well 33E116.

Natural gamma-radiation logs were used to correlate regional hydrogeologic units and lithostratigraphic units to formations and water-bearing sediments penetrated in the corehole at well 33E116. The use of natural gamma-radiation logs, in conjunction with the core, allows much greater confidence in correlation of geologic units in the corehole with units in other wells than would otherwise be expected from comparing drill cuttings and drilling logs. The increase in confidence of correlation is good; however, the obvious deflections or "kicks" on geophysical logs do not necessarily coincide with formation tops, therefore, interpolation from existing data is needed to determine the position of lithostratigraphic and hydrogeologic units (Gregg and Zimmerman, 1974). Correlation with the lithostratigraphy of Huddlestun (1988) is based on the lithologic description and a natural gamma-radiation log from well 34E001, located on the southern end of Cumberland Island (Georgia Geologic Survey well number 3426) and copies of Huddlestun's original notes on file at the USGS, Atlanta, Ga.

Undifferentiated Surficial Sands and Satilla Formation (Holocene and Pleistocene)

The Holocene and Pleistocene sediments in the study area are not differentiated in this report due to the similar lithologic and geophysical nature of these sediments and the lack of paleontologic control; however, it is likely that both the Satilla Formation, and the undifferentiated surficial sands of Huddlestun (1988) are present at the site. In the study area, these Quaternary sediments generally consist of well sorted, fine to very fine quartz sand. Some organic rich lenses form a laterally extensive but discontinuous layer at depths of about 5 to 10 ft below land surface (29 to 24 ft above sea level). Pelecypod shells are present but are not abundant within these sediments. There is no distinct geophysical marker at the base of the Quaternary sediments; however there is a distinct stratigraphic horizon within the Quaternary sediments that is a partially cemented, reddish brown, iron stained sand typical of the Satilla Formation. The thickness of the Quaternary sediments across the site is generally from 35 to 45 ft.

Cypresshead Formation (Pliocene (?))

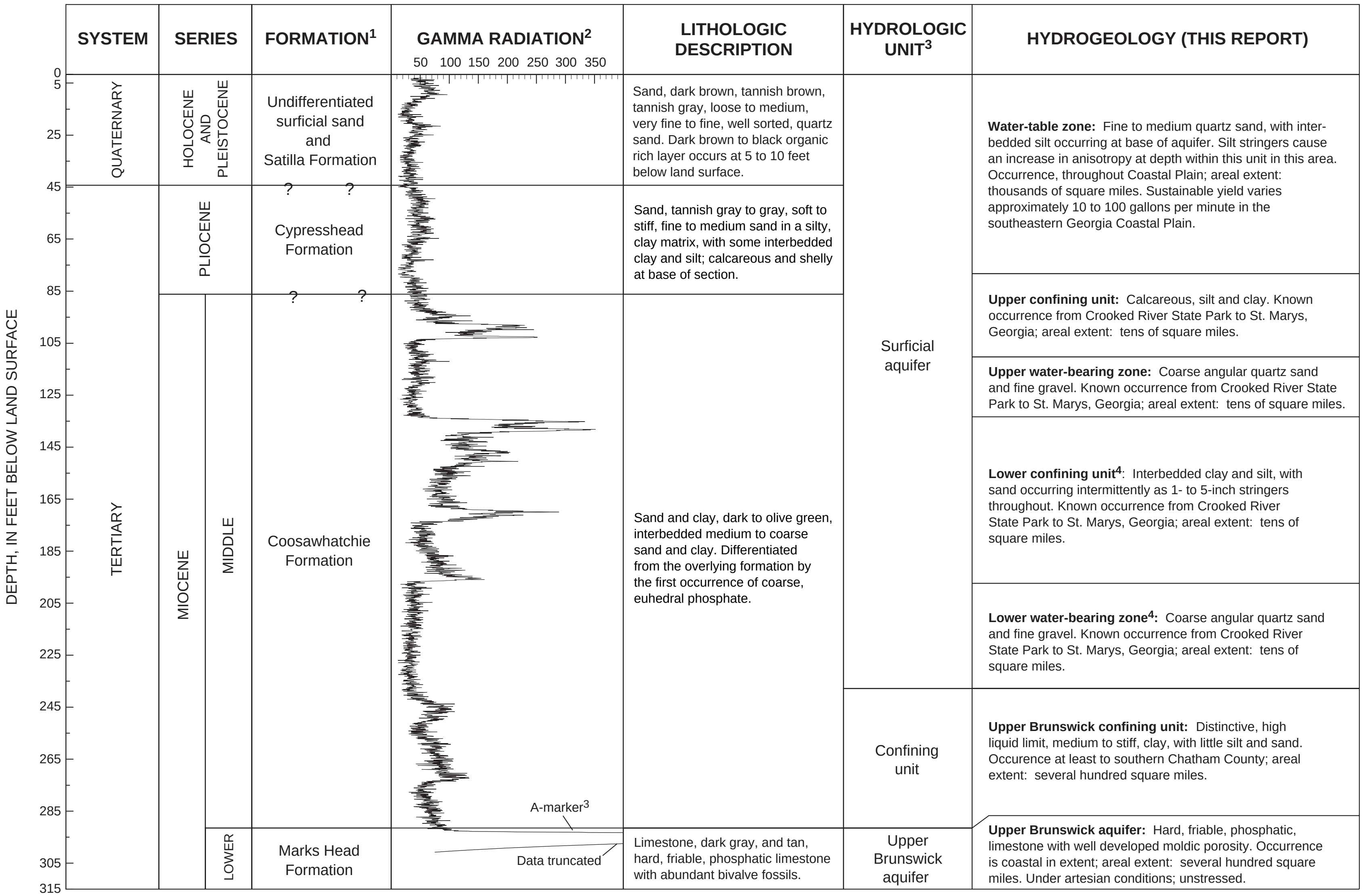
Pliocene sediments identified at the site are consistent with the Huddlestun's (1988) description of the Cypresshead Formation and consist of fine to medium sand that grades downward into a sandy, clayey silt. The base of the unit is characterized by thin clay and silt interbeds that become calcareous and shelly with depth. The Pliocene sediments are differentiated herein based primarily on lithology; specifically, an increase in the grain size of the coarse fraction, an increase in the clay content, and a decrease in both cementation and iron staining. Pliocene sediments range in thickness from about 35 to 45 ft, ranging in depth from about 62 ft below land surface (31 ft below sea level) in well 33E065 to about 85 ft below land surface (55 ft below sea level) in well 33E116 (fig. 3). Based on well cuttings, Gregg and Zimmerman (1974) reported that Pliocene sediments are present at a depth of 140 ft below land surface (135 ft below sea level) near Brunswick in Glynn County, Ga.

Coosawhatchie and Marks Head Formations (Miocene)

Miocene sediments and rocks consist of interbedded, dark to olive green, medium to coarse sand and clay, and a dark yellowish gray, calcareous, cherty limestone at the base of the sampled section. These sediments were identified by Huddlestun (1988) as the middle Miocene Coosawhatchie Formation, and the lower Miocene Marks Head Formation (fig. 4).

Coosawhatchie Formation (middle Miocene)

In the study area, the top of the middle Miocene Coosawhatchie Formation is identified by the first occurrence of subrounded coarse sand to fine pebbles, phosphate, and by a color change to a distinctive dark to olive green as described by Huddlestun (1988). The phosphate causes a significant increase in natural gamma radiation in well 33E116 (fig. 4) beginning at 85 ft below land surface (55 ft below sea level). Middle Miocene sediments typically consist of massive sand and clay. In well 33E116, the middle Miocene sediments occur from about 85 ft below land surface (55 ft below sea level) to 293 ft below land surface (273 ft below sea level), and have a thickness of about 208 ft.



[1] From Huddlestun, 1988.
[2] Natural gamma values reported in counts per second.
[3] From Clarke and others, 1990.
[4] Water-bearing properties based on lithology, no hydraulic data currently available.

Figure 4. Lithostratigraphy, hydrogeology, and natural gamma radiation log of well 33E116, Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia.

Marks Head Formation
(lower Miocene)

The top of the lower Miocene Marks Head Formation is marked by a change in lithology from the unconsolidated clay of the middle Miocene to a hard, fossiliferous, calcareous, cherty limestone of the lower Miocene. This limestone unit is indicated on geophysical logs by a distinct increase in natural gamma radiation that is an indicator of the top of the lower Miocene throughout the Georgia coastal area (Clarke and others, 1990) (fig. 4). This gamma deflection termed the “A” marker (Wait, 1962; Clarke and others, 1990), occurs because of permineralization of shells with fluorapatite (a phosphate-bearing mineral). This very strong “A” marker is well documented in the geologic literature in Georgia, and is the shallowest of four such diagnostic geophysical signatures used for correlation in the Georgia coastal area. The top of the lower Miocene was encountered at a depth of 303 ft below land surface (273 ft below sea level) in the corehole which was terminated at a depth of 310 ft (270 ft below sea level). Because the corehole at well 33E116 did not fully penetrate the lower Miocene sediments at Site 11, the total thickness is not known. However, Clarke and others (1990) reported the thickness of Miocene sediments to be about 225 ft in well 33E039 about 1.5 miles southeast of the study area.

Hydrogeologic Units

Hydrogeologic units in the study area include the surficial aquifer (Miller, 1986; Krause and Randolph, 1989; and Clarke and others (1990)); the upper and lower Brunswick aquifers (Clarke and others, 1990); and the Floridan aquifer system. In this report, only the surficial and upper Brunswick aquifers described by Clarke and others (1990) are discussed.

Surficial Aquifer

In the study area, the surficial aquifer is comprised of the undifferentiated surficial sand, the Satilla Formation, the Cypresshead Formation, and most of the Coosawhatchie Formation of Huddlestun (1988) (fig. 4). In southeastern Georgia and northeastern Florida, water in the surficial aquifer occurs under both water-table and confined (artesian) conditions (Clarke and others, 1990; Spechler, 1994)—this generality also holds true for the surficial aquifer at Site 11. For the purposes of this report, the surficial aquifer is informally divided into the following water-bearing zones that from land surface are: (1) the water-table zone; (2) the confined, upper water-bearing zone; and (3) the confined, lower water-bearing zone. These water-bearing zones are separated by confining units consisting of clay and silt (fig. 4).

Water-table zone

The water-table zone consists of the fine to medium sand of the undifferentiated surficial sand, the Satilla Formation, and the upper part of the Cypresshead Formation (fig. 4). Water in these sediments occurs under unconfined (water-table) conditions. The thickness of the water-table zone generally varies between 60 to 80 ft across the study area, largely as a result of variations in topography. In addition, because the thickness of the zone is computed from the water-table surface to the base of the zone, temporal variations in the water table also affect the thickness of the zone. The base of the water-table zone was penetrated at a depth of 77 ft in well 33E116. Using natural gamma radiation logs, the water-table zone is recognized, in this study, as far north as well 33E008, as far south as well 33E040 (figs. 2 and 5), as far east as well 33E037, and as far west as well 33E027 (figs. 2 and 6). It must also be noted that there is a resistance to vertical ground-water flow that occurs between about 10 to 40 ft below sea level (see report subsection titled, “Vertical Distribution of Hydraulic Head” for further discussion). This resistance is the basis for further division of the water-table zone, into upper and lower parts; whereby, the water-table zone is conceptualized as two distinct but not separate zones.

The water-table zone yields water to many small diameter driven and jetted wells in the Crooked River subdivision, immediately west of site 11 (fig. 2) (U.S. Department of the Navy, 1994). Sustained yields for these wells are uncertain, but data from contaminant-recovery wells that penetrate the water-table zone at Site 11, have variable yields ranging from 5 to 39 gallons per minute (gal/min), with higher yields likely (L.B. Harris, ABB-Environmental Services, oral commun., 1997). In addition, similar wells completed in the surficial aquifer yield from 5 to 140 gal/min in Glynn County (Gregg and Zimmerman, 1974).

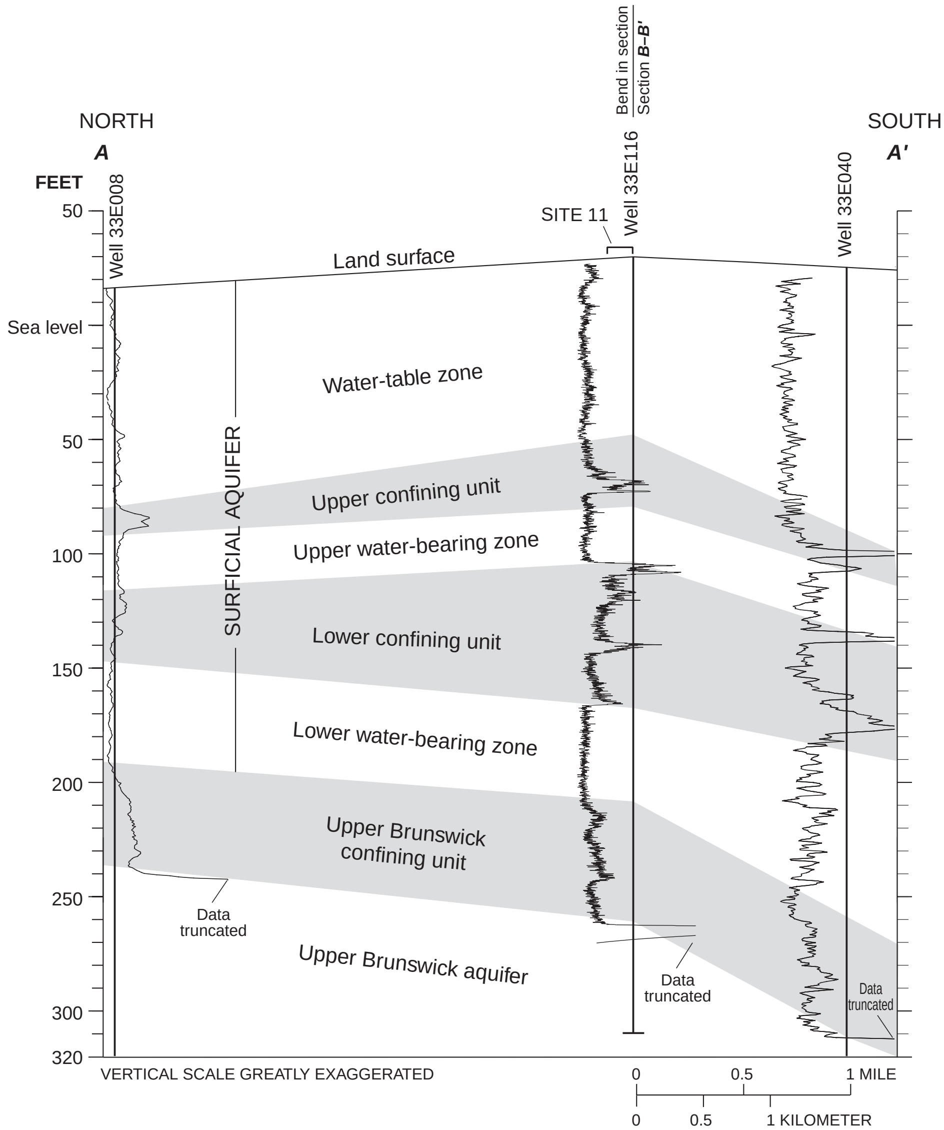


Figure 5. Hydrogeologic section *A–A′* showing the surficial and upper Brunswick aquifers, and natural gamma radiation logs for selected wells in the vicinity of Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia (line of section shown in figure 2).

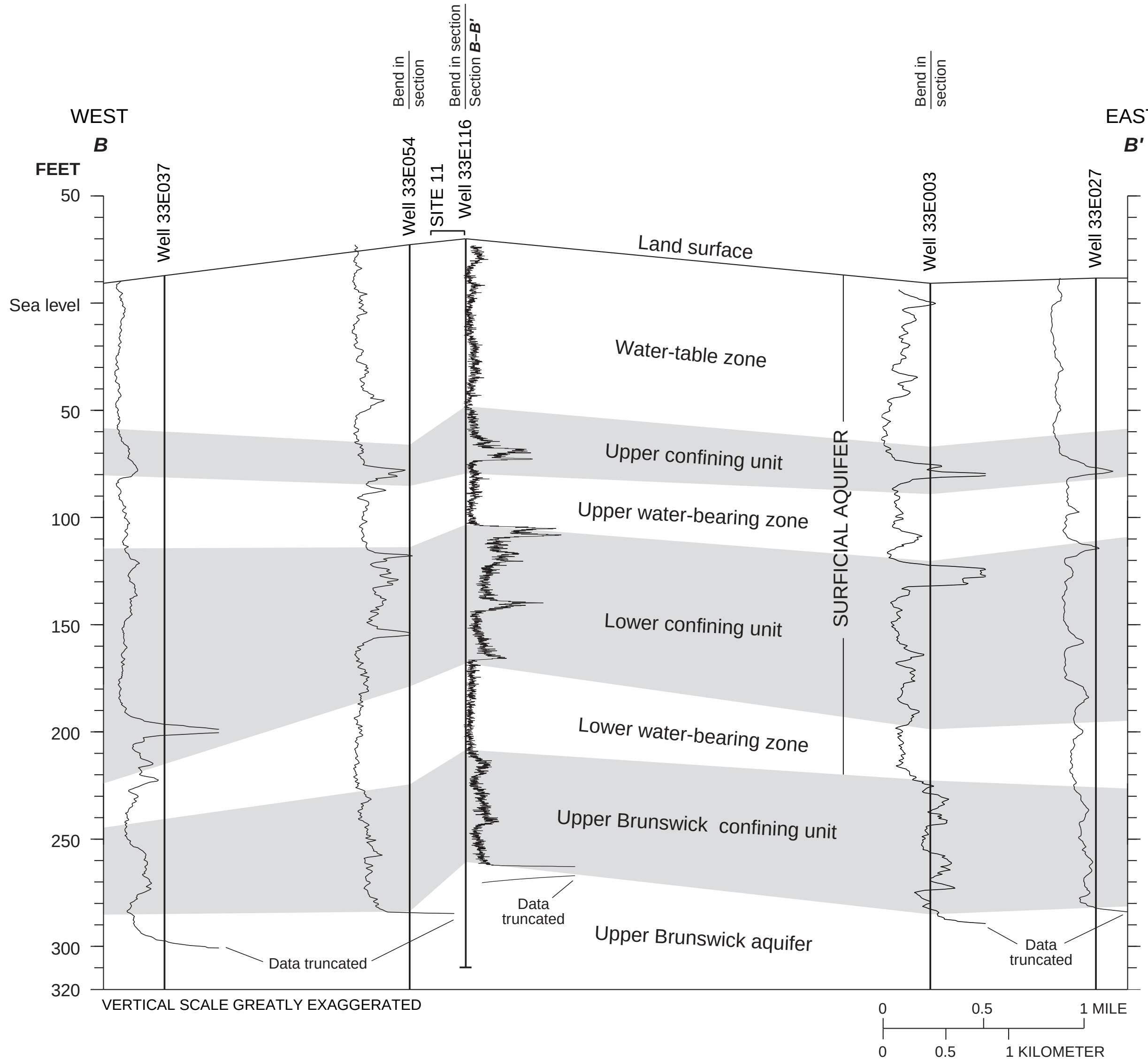


Figure 6. Hydrogeologic section *B–B′* showing the surficial and upper Brunswick aquifers and natural gamma radiation logs for selected wells in the vicinity of Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia (line of section shown in figure 2).

One method used to determine the hydraulic properties of an aquifer, is an aquifer test and subsequent mathematical analysis of data. At site 11, a constant discharge aquifer test was conducted for 31 hours at a discharge rate of 30 gal/min in May 1996 in the water-table zone using well 33E119 (fig. 3) as the pumped well and six observation wells. Although, six observation wells were monitored during the test, steady-state conditions were reached only in well 33E081 before rainfall necessitated termination of the test (fig. 3). Therefore, data were analyzed only for well 33E081 using the graphical analytical solutions of Neuman (1972) and Jacob (1950) as outlined in Kruseman and de Ridder (1990). Applying the Neuman (1972) method to both drawdown and recovery (residual drawdown) data, hydraulic conductivities computed range from about 6.7 to 7.4 feet per day (ft/day) in well 33E081 (table 2). Applying the Jacob (1950) method to both drawdown and recovery (residual drawdown) data, computed hydraulic conductivities range from about

12.1 to 13 ft/day in well 33E081 (table 2). It is likely that the values computed using the Neuman (1972) method are an underprediction of field values because the observation well (33E081) did not fully penetrate the aquifer. On the other hand, it is likely that the values computed using the Jacob method are an overprediction of field values, because the zone is unconfined. For these reasons, aquifer properties from the test are reported as a range of hydraulic conductivities.

Table 2. Values of hydraulic conductivity derived from an aquifer test in the water-table zone, Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia, May 1996

Well number	Hydraulic conductivity[1/] (feet per day)	Hydraulic conductivity [2/] (feet per day)
[3/]33E081	6.7	7.4
[4/]33E081	12.1	13

[1/]Derived from drawdown data.
[2/]Derived from residual drawdown data.
[3/]Analysis completed using methodology of Neuman (1972).
[4/]Analysis completed using methodology of Jacob (1950).

Upper water-bearing zone

The confined upper water-bearing zone is separated from the overlying water-table zone by the upper confining unit, and from the confined lower water-bearing zone by the lower confining unit (fig. 4). The upper confining unit consists of the lower silt and clay part of the Cypresshead Formation and the upper silt and clay part of the Coosawhatchie Formation (fig. 4). In well 33E116 (fig. 4), the top of the upper confining unit occurs at a depth of about 77 ft below land surface, and the bottom of the unit occurs at a depth of about 110 ft—a total thickness of about 33 ft (figs. 4, 5, and 6). The areal extent of this unit is not well defined; however, the unit was correlated, using natural gamma radiation logs to as far north as well 33E008, as far south as well 33E040, as far west as well 33E037, and as far east as well 33E027 (figs. 2, 5, and 6).

The confined upper water-bearing zone consists of medium gray, loose, fine to coarse, poorly sorted, subangular, quartz sand and fine gravel. The top of the sand occurs in the upper part of the of the Coosawhatchie Formation at a depth of about 110 ft below land surface and continues to a depth of about 132 ft in well 33E116; thickness of this location is about 22 ft (figs. 4, 5, and 6).

A single-well aquifer test was conducted on May 29, 1997, in the upper water-bearing zone using well 33E116 and the data were analyzed with procedures modified from Hantush (1964) and Bierschenk (1963). Because of the lack of observation wells completed in the upper water-bearing zone, data from a single well, step-drawdown aquifer test and recovery test were analyzed. The results indicate the specific capacity at a discharge rate of 15 gal/min is about 0.7 gallons per minute per foot and the transmissivity is about 180 feet squared per day (ft^2/day). The transmissivity of the step-drawdown test is in accord with the transmissivity estimate of about 170 ft^2/day, derived from recovery-test data. Results from this aquifer test suggest that yields for the upper water-bearing zone could exceed 20 gal/min from a 4-inch diameter well.

Lower water-bearing zone

The confined lower water-bearing zone is separated from the upper water-bearing zone by the silt and clay of the lower confining unit that lies in the middle part of the Coosawhatchie Formation. The contact between the upper water-bearing zone and the underlying silt and clay of the lower confining unit is transitional, but begins at a depth of about 132 ft below land surface in well 33E116 (fig. 4); the lower confining unit is about 65 ft thick at this location (figs. 4, 5, and 6). The areal extent of both the lower confining unit and the lower water-bearing zone was defined using natural gamma radiation logs from wells 33E008, 33E040, 33E037, and 33E027. However, these units likely are more extensive than shown herein. It also must be noted that because of the lack of hydrologic data for this unit, specific hydrologic properties, including degree of confinement, are unknown.

The confined lower water-bearing zone consists of loose, subangular to angular, coarse to very coarse, quartz sand, and fine quartz gravel within the lower part of the Coosawhatchie Formation. The top of this zone occurs at a depth of about 195 ft below land surface at well 33E116; the zone is about 42 ft thick at this location. The contact with the upper Brunswick confining unit of Clarke and others (1990) is at a depth of about 237 ft (figs. 4, 5, and 6). Data for water-bearing properties are limited to yields from drillers' acceptance tests of wells completed in the lower water-bearing one on NSB Kings Bay. These yields range from 75 to 100 gal/min from 6-inch diameter screened wells (W. Sapp, Jr., Woodrow Sapp Water Well Contractor, Inc., written commun., 1998).

Upper Brunswick Confining Unit

Underlying the lower water-bearing zone is a distinct, medium to stiff, clay that was first identified by Clarke and others (1990), who referred to the clay as the unnamed confining unit overlying the upper Brunswick aquifer. In this report, the confining unit is referred to as the upper Brunswick confining unit. The top of the upper Brunswick confining unit was penetrated at a depth of 237 ft below land surface in well 33E116; extends to a depth of about 291 ft, having a thickness of 54 ft (fig. 4). This unit consists of the basal section of the Coosawhatchie Formation, and is relatively extensive, occurring at least from the NSB Kings Bay, to as far north as southern Chatham County, Ga. (Clarke and others, 1990).

Upper Brunswick Aquifer

In the study area, the upper Brunswick aquifer consists of the upper limestone and coarse sand section of the lower Miocene Marks Head Formation (Huddlestun, 1988). The top of the upper Brunswick aquifer was penetrated at a depth of about 293 ft below land surface at well 33E116 and can be distinguished on geophysical logs as a zone of low natural gamma radiation beneath the “A-marker” (fig. 4). The base of the upper Brunswick aquifer was not penetrated in well 33E116 because the hole was terminated at 310 ft; however, Clarke and others (1990) indicated that in wells 33E039 and 33E040—about 2 miles southeast of the study area—the upper Brunswick aquifer is about 60 ft thick. The upper Brunswick aquifer is relatively extensive, and is present at least from the NSB Kings Bay, to as far north as southern Chatham County, Ga. (Clarke and others 1990).

Ground-Water Levels and Precipitation Data

Ground-water-level and precipitation data collected at Site 11 illustrate water-level trends and the distribution of hydraulic head in the water-table zone of the surficial aquifer. In October 1995, continuous water-level recorders were installed in wells 33E070 and 33E071; an additional recorder was installed in well 33E107 in December 1995 (fig. 3). A precipitation gage was installed near well 33E071 in February 1995 (figs. 3 and 7). The data from the water-level recorders were used to determine water-level fluctuations and trends in the water-table zone. In addition, periodic water-level measurements were obtained in wells screened in the water-table zone. The vertical distribution of hydraulic head in wells completed at various depths within the water-table zone was measured to determine hydraulic separation and possible resistance to vertical ground-water flow. Finally, water levels measured in well 33E079 (fig. 3)—completed at the base of the water-table zone—and in well 33E116—completed in the confined upper water-bearing zone—were compared to evaluate hydraulic separation between the water-table zone and the upper water-bearing zone.

Seasonal Fluctuations in Water Levels

Hydrographs were used to evaluate ground-water-level and seasonal fluctuations in the water-table zone from October, 1995 to April 1997 (fig. 7). Seasonal fluctuations, indicative of water-table conditions, are apparent from the water-level response in wells 33E070, 33E071 and 33E107 completed in the water-table zone (fig. 7). Generally, ground-water levels peak during periods of high precipitation—for example, early October 1996; and recede during periods of low precipitation—for example, November 1996—April 1997 (fig. 7). October through May generally are the dryer months, when normal rainfall (Brown, 1984) ranges from 2 to 4 inches per month. Precipitation data at Site 11 are consistent with seasonal patterns described by Brown (1984) who reported that 60 percent of annual rainfall occurs from June through September, with a range of about 6 to 8 inches per month. During this study, annual water-level fluctuations in wells 33E070, 33E071, and 33E107 were about 4 ft. No evidence of tidally induced water-level fluctuations is apparent from these data.

Vertical Distribution of Hydraulic Head

Discrete water-level measurements from wells that are in close proximity and have differing screen depths (well clusters), allows the computation of vertical hydraulic gradients between those wells. By measuring hydraulic head differences between wells and the thickness of the water-bearing unit over which the head difference is measured, vertical hydraulic gradients can be calculated. Measurements made at four cluster sites in the water-table zone indicate that in all instances heads are lower with depth, indicating a downward potential for flow (fig. 8). Measurements made at the cluster site that penetrates both the water-table zone and the confined upper water-bearing zone also indicate a downward potential for flow (fig. 9).

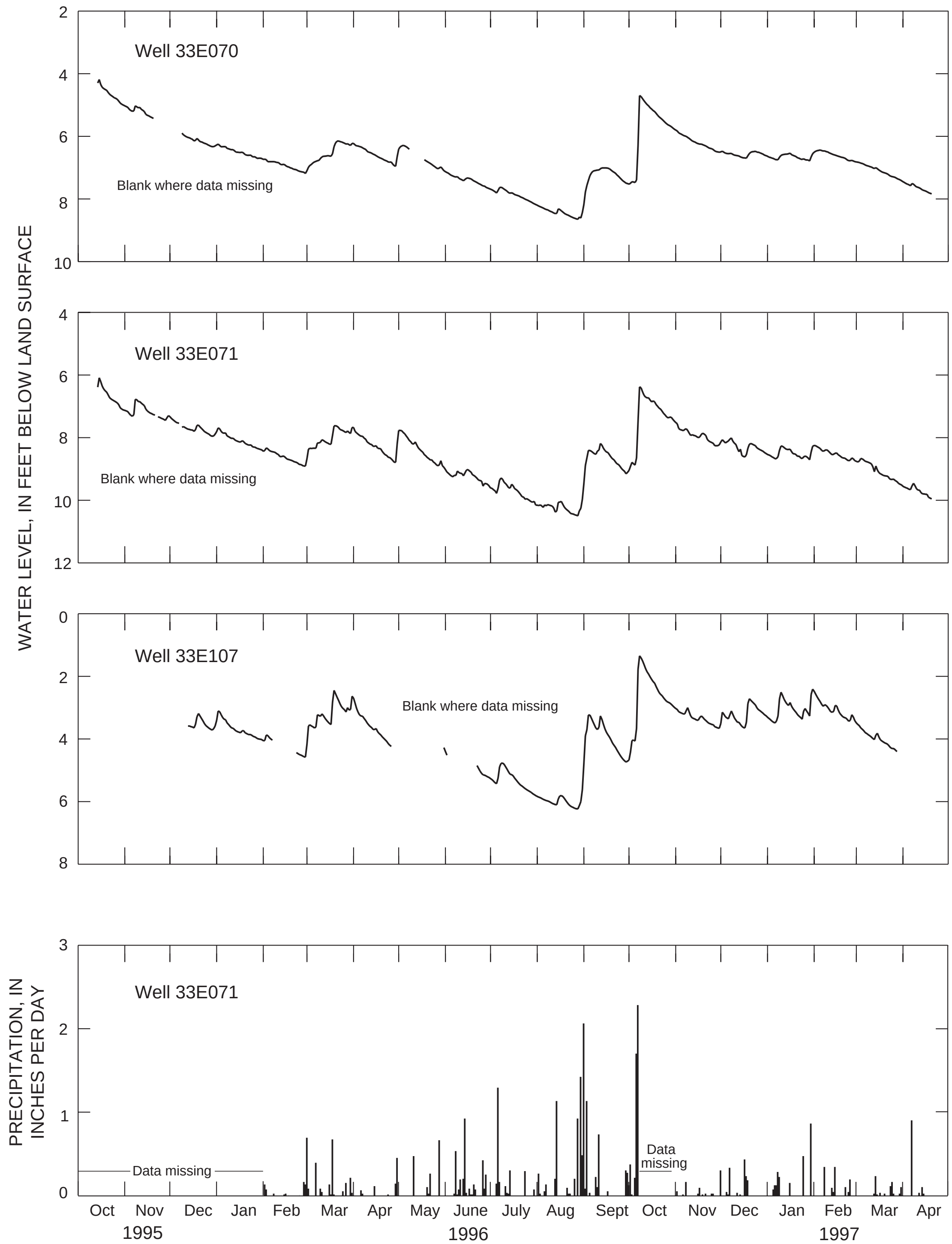


Figure 7. Water-table fluctuations in wells 33E070, 33E071, and 33E107 and daily precipitation at well 33E071, Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia, October 1995 to April 1997.

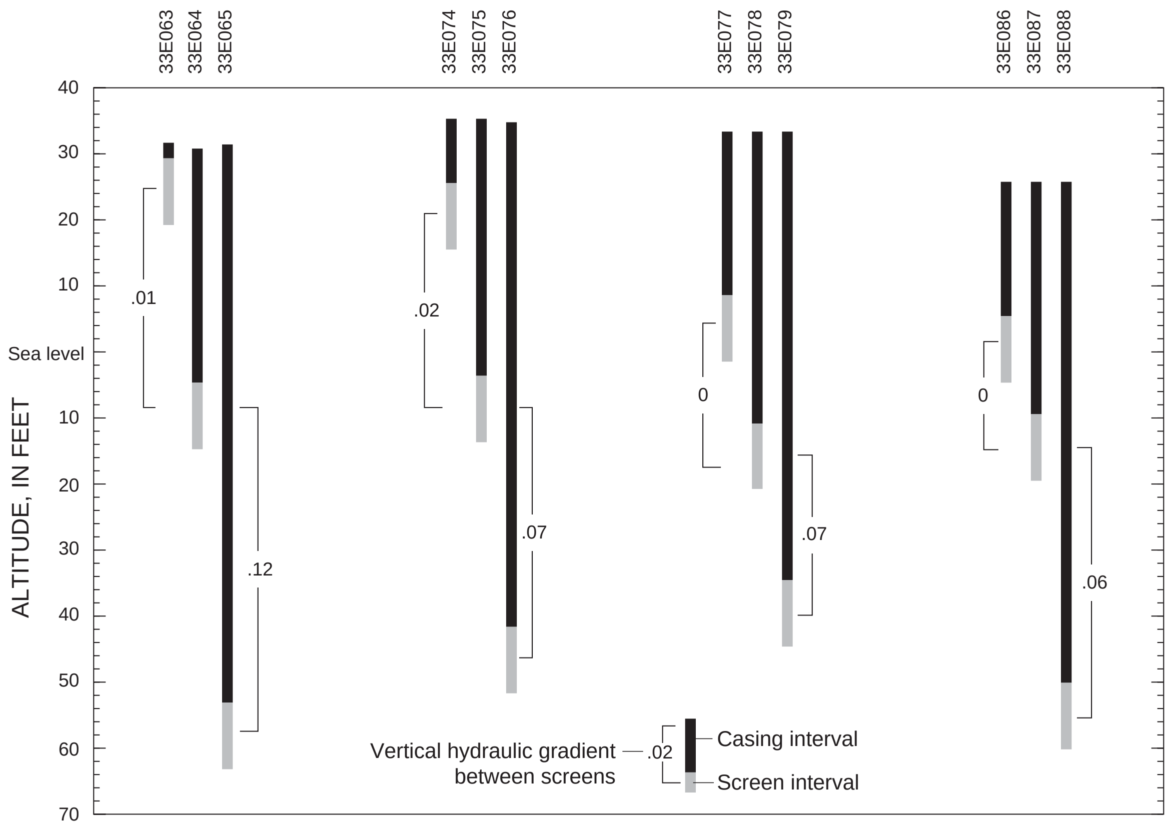


Figure 8. Vertical hydraulic gradients and screened intervals for selected well clusters completed in the water-table zone at Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia (H.H. Zehner, U.S. Geological Survey, written communication, 1995).

Comparison of hydraulic gradients computed for wells completed in the upper, middle, and lower parts of the water-table zone indicates a significant change in gradient occurs between about 10 to 40 ft below sea level (well depths of about 40 to 70 ft) (H.H. Zehner, U.S. Geological Survey, written commun., 1995). This change in gradient indicates that a restriction to vertical flow occurs between these depths (resolution of less than 30 ft is not possible due to the transitional nature of the lithologic contact, the placement of the monitor well screens, and the 10-ft long screen lengths). Increased clay content and subsequent lower permeability of the Cypresshead Formation near this altitude is the probable cause of the flow restriction.

In addition to comparison of hydraulic heads within the water-table zone, heads between the water-table zone and the confined upper water-bearing zone were measured and compared to determine vertical head separation between these units. A 7-ft difference in hydraulic head was measured between well 33E079 (completed in the lower part of the water-table zone) and well 33E116 (completed in the confined upper water-bearing zone) (fig. 9). These data confirm that these two wells are completed in different water-bearing zones. Also, during the step-drawdown aquifer test in well 33E116, there was no water-level response apparent in well 33E079, indicating a high degree of hydraulic separation between the water-table and confined upper water-bearing zone.

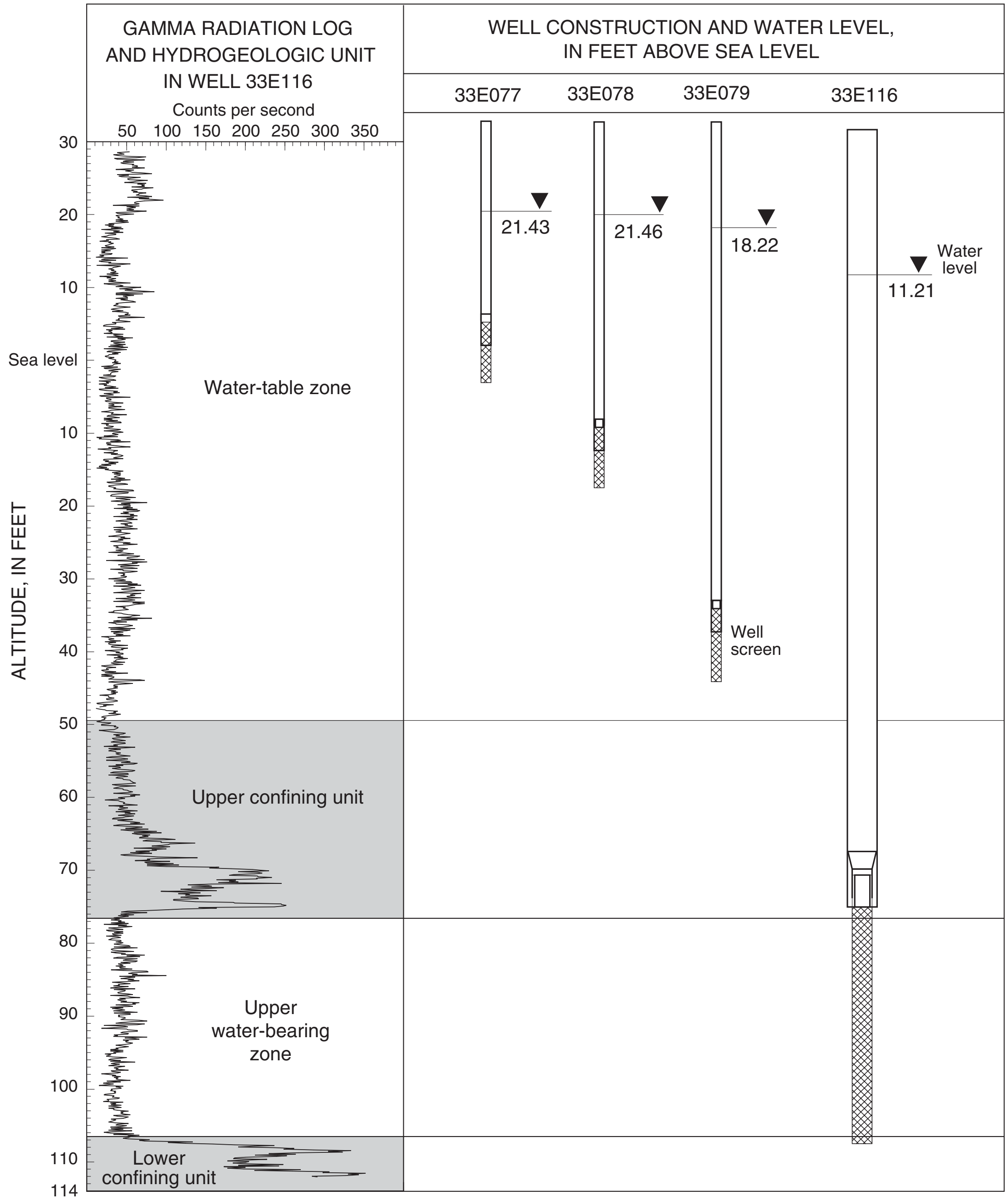


Figure 9. Water-level altitudes in wells 33E077, 33E078, 33E079, and 33E116, illustrating separation of water-bearing units; and natural gamma radiation log for well 33E116, Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia.

Water Table

The water table was delineated using synoptic water-level measurements in selected wells. Contours indicate that there is an axial symmetric water-table “high” that changes position seasonally, but is generally located to the east of and beneath the eastern edge of the landfill (figs. 10, 11, and 12). This conclusion agrees with the observation that ground water under water-table conditions generally is a subdued replica of land-surface relief (Heath, 1983). The site of the former Camden County landfill (Site 11) is a topographic high; therefore, the water table beneath it and to the east has the highest water-table altitudes.

Because of seasonal water-level fluctuations, the configuration of the water table varies in both space and time. These variations are shown in the water-table maps for April 15 and July 2, 1996, and April 14–15, 1997 (figs. 10, 11, and 12). The lateral ground-water movement can be projected based on the shape of the water-table high beneath the former Camden County landfill. Precipitation falling on the area of the water-table high generally runs off in a radial pattern away from the area of the water-table high. Ground-water gradients to the north, south, and east of the water-table high are less than those to the west. Data—in tandem with the relatively flat topography to the east—would argue that ground water on the west side of the water-table high is likely to flow away from the water-table high at a greater rate than to the east.

Estimated Ground-Water Velocities

Estimates of ground-water velocities (hydraulic gradients) can be derived from water levels measured in selected wells located along the generalized direction of ground-water flow (figs, 10, 11, and 12), and together with estimates of hydraulic conductivity, can be used to calculate the Darcy velocity of ground-water flow. The Darcy velocity is a measure of the rate at which a given molecule of water will flow a given distance through an idealized aquifer, the equation for which is:

$$v = K(dh \ \S \ dl) \tag{1}$$

where

v	=	the Darcy velocity,
K	=	the hydraulic conductivity, and
dh/dl	=	the hydraulic gradient.

The Darcy velocity does not account for the porosity of an aquifer. To obtain the average linear velocity of ground-water movement, one must divide the Darcy velocity by the effective porosity (as a decimal fraction) of the aquifer sediments. For example, assuming an effective porosity of 20 percent (0.2), the average linear velocity would be about five times greater than the Darcy velocity. Because no site-specific effective-porosity data exist, only estimated Darcy velocities are reported herein (table 3). These velocity estimates are based on hydraulic gradients derived from the April 15, 1996 and April 14–15, 1997 water levels (figs. 10 and 12); and hydraulic conductivities of 13 ft/d and 7 ft/d (hydraulic conductivities rounded from residual drawdown data, table 2).

Table 3. Estimates of Darcy velocity in the water-table zone, Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia, April 15, 1996 and April 14–15, 1997

Generalized flow direction	Hydraulic conductivity from aquifer-test results (feet per day)	Hydraulic gradient (foot per foot)	Sampling date	Estimated Darcy velocity (feet per year)
West	13	0.006	April 15, 1996	28
	7	.006	April 15, 1996	15
	13	.003	April 14-15, 1997	14
	7	.003	April 14-15, 1997	7
East	13	.0016	April 15, 1996	8
	7	.0016	April 15, 1996	4
	13	.0013	April 14-15, 1997	6
	7	.0013	April 14-15, 1997	3

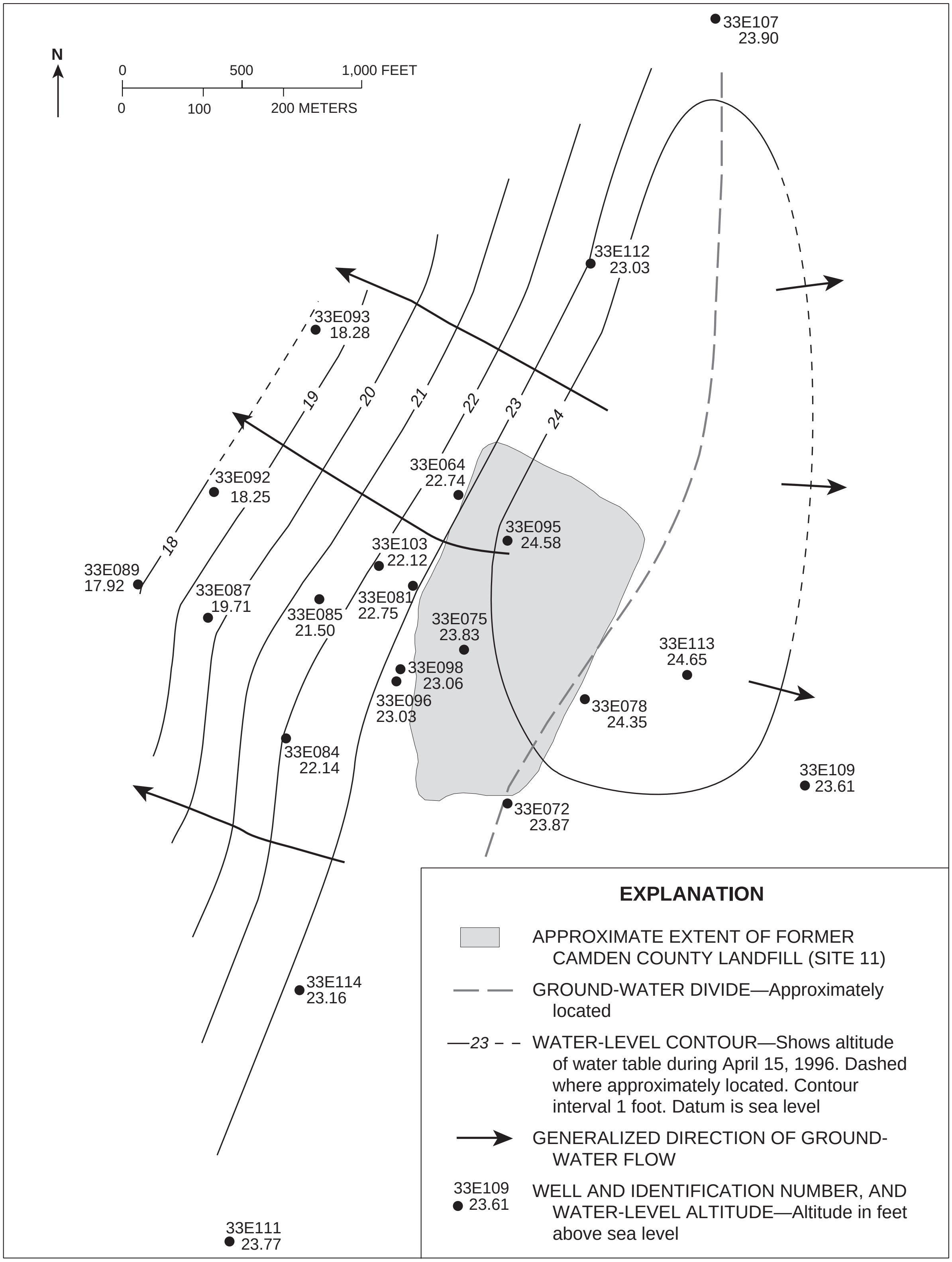


Figure 10. Altitude of water table, Site 11, Naval Submarine Base Kings Bay, Camden County, Gerogia, April 15, 1996.

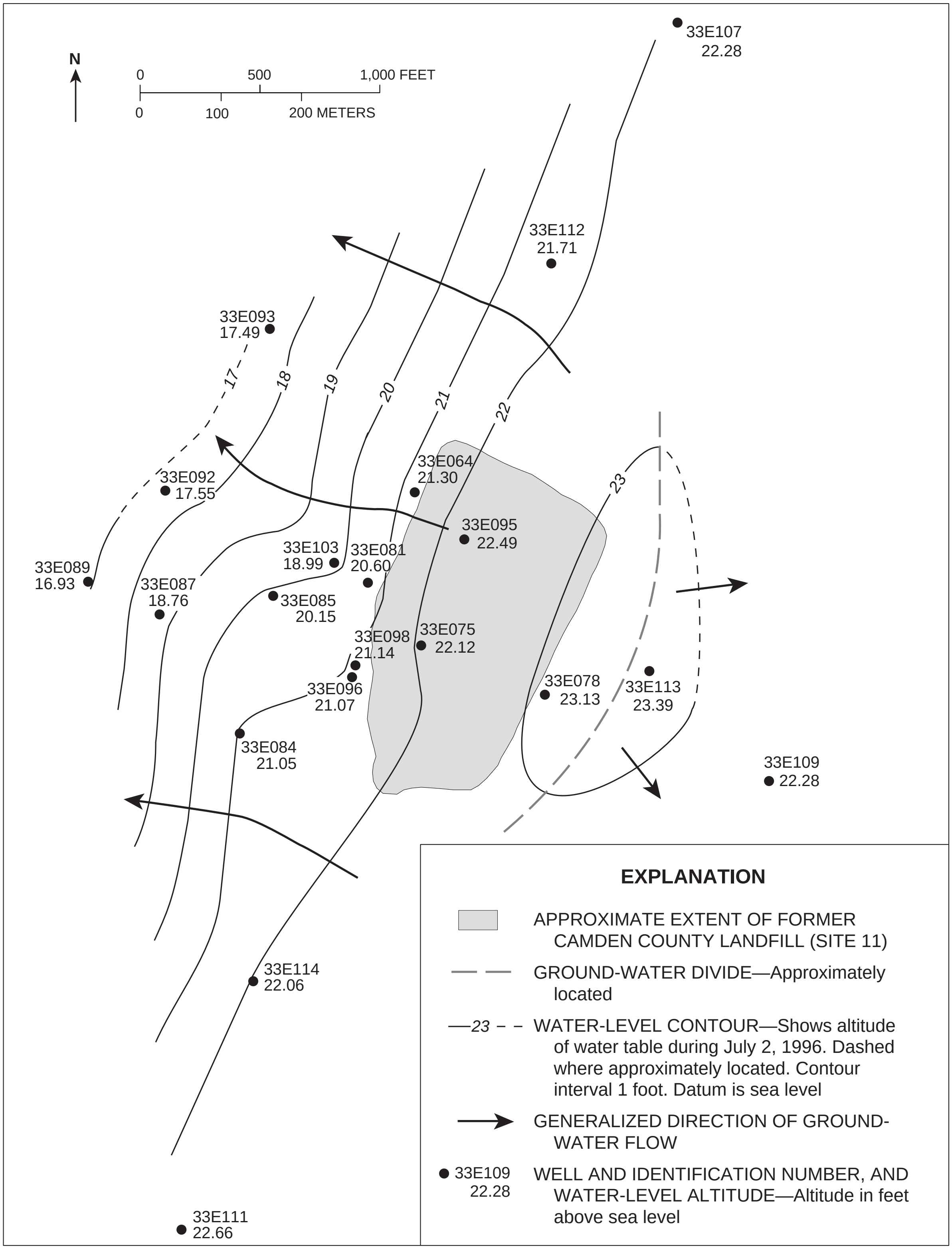


Figure 11. Altitude of water table, Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia, July 2, 1996.

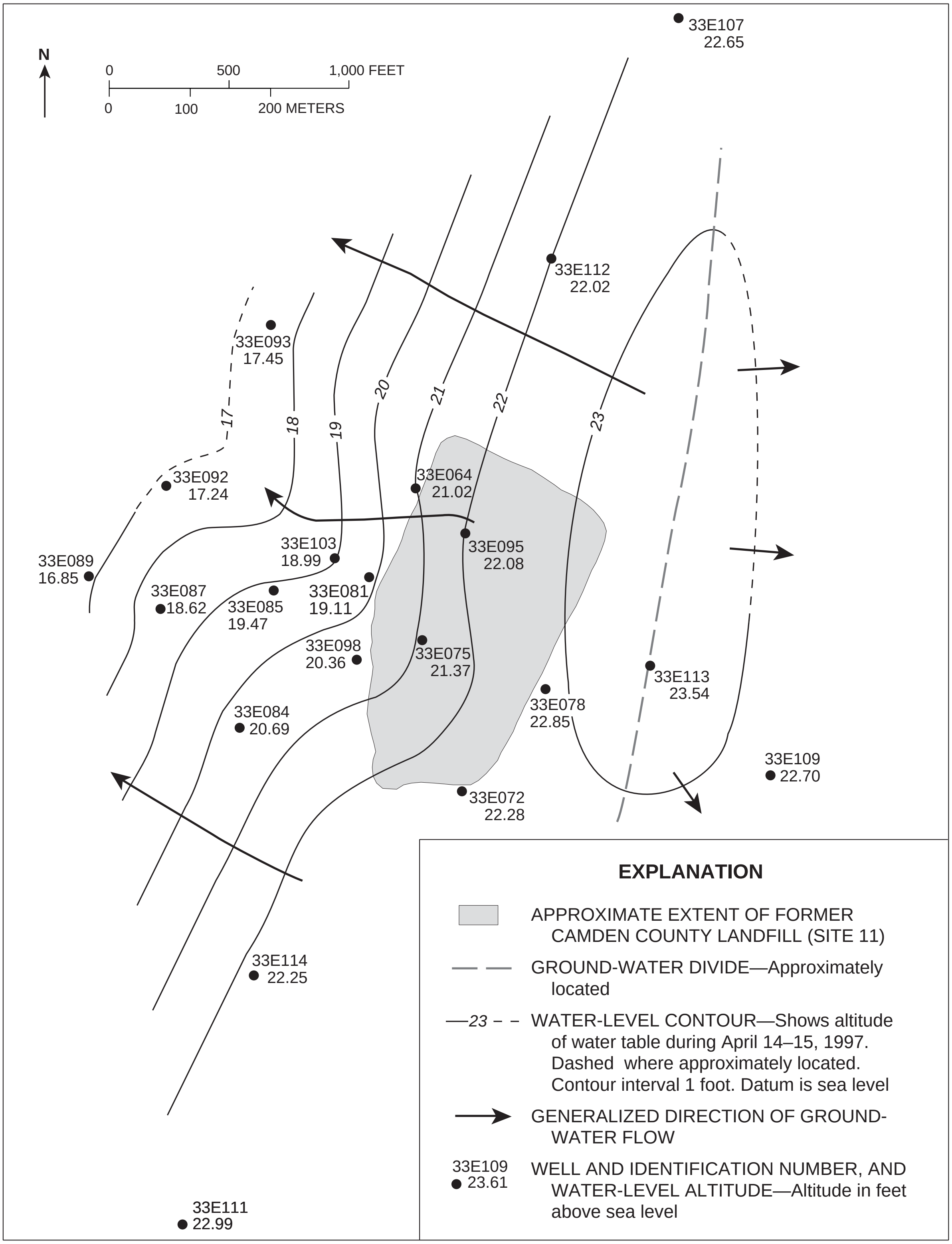


Figure 12. Altitude of water table, Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia, April 14–15, 1997.

Given consistent lithology, Darcy velocities vary with the shape of the water table. On the west side of the water-table high (figs.10, 12), estimated Darcy velocities range from a high of about 28 ft/yr—when the hydraulic gradient is steep and the hydraulic conductivity value chosen is high—to a low of about 7 ft/yr—when hydraulic gradients are the lowest and the hydraulic conductivity value chosen is low (table 3). On the east side of the water-table high (figs. 10, 12), estimated Darcy velocities range from a high of about 7 ft/yr—when the hydraulic gradient is steep and the hydraulic conductivity value chosen is high—to a low of about 3 ft/yr—when hydraulic gradients are the lowest and the hydraulic conductivity value chosen is low (table 3).

Essentially, these data indicate that, assuming that lithology is consistent, Darcy velocities (in both the east and west directions) increase during periods when the water table is high and decrease when the water table is low. In addition, at any given time, ground water on the western side of the water-table high flows at a faster Darcy velocity than does ground water on the eastern side of the water-table high. Therefore, the flow velocity varies with time, much as the shape of the water table varies with time.

These Darcy velocity data are best used for relative comparison, as above. Because these data were based on hydraulic conductivities derived from one aquifer test and the effective porosity of the aquifer is unknown, caution should be used when applying these data to predictive calculations until a more thorough understanding of the aquifer hydraulic properties is obtained.

Ground-Water Quality

Results from the chemical analysis of ground-water-quality samples from wells completed in the water-table and confined upper water-bearing zones were used to compare the geochemical variability of ground water in the two zones. Water samples from selected wells were analyzed for dissolved concentrations of inorganic constituents (table 4). Field properties including pH, specific conductance, and water temperature were measured onsite prior to collection of the samples.

Ground-water-quality properties provide a basis for comparison with published ground-water-quality data. Water from the eight wells sampled is fresh, with dissolved-solids concentrations of less than 115 milligrams per liter (mg/L), and no major ionic concentrations exceeding the U.S. Environmental Protection Agency (EPA) and Georgia Environmental Protection Division (EPD) primary or secondary maximum contaminant levels for drinking water (U.S. Environmental Protection Agency, 1996; Georgia Environmental Protection Division, 1993). However, pH in wells 33E077, 33E108, 33E109, 33E110, and 33E111 are below the EPA and EPD secondary drinking-water standards of 6.5.

Graphical methods of data presentation provide a means for distinguishing the chemical properties of ground-water from different water-bearing zones. A trilinear diagram showing the percentage composition (in milliequivalents per liter) of selected major cations and anions, as well as dissolved-solids concentrations of those constituents (in mg/L) is shown in figure 13. Patterns evident from figure 13 include: (1) dissolved-solids concentrations for wells completed in the upper part of the water-table zone are generally lower (ranging from 28 to 71 mg/L; table 4) than dissolved solids concentrations for wells completed in the lower part of the water-table zone and the upper confined zone (ranging from 100 to 114 mg/L respectively; table 4); and (2) ratios of major ions indicate that the ground water can be grouped into two distinct types—the sodium-chloride water derived from six samples of the upper part of the water-table zone; and the calcium-bicarbonate water from two samples in the lower part of the water-table zone and the confined upper water-bearing zone. These differences in water chemistry lend further evidence to the hydraulic separation between the water-bearing zones described previously.

Table 4. Field properties and inorganic constituents in water from selected test wells at Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia, April 15, 1997

[analyses by U.S. Geological Survey, Atlanta, Georgia; *units*—mg/L, milligrams per liter; µS/cm, microsiemens/centimeter; < less than]

Field properties and inorganic constituents, in units	Test-well number and water-bearing zone							
	33E077, Water-table zone	33E078, Water-table zone	33E079, Lower water-table zone	33E108, Water-table zone	33E109, Water-table zone	33E110, Water-table zone	33E111, Water-table zone	33E116, Upper water-bearing zone
Alkalinity, as calcium carbonate, mg/L	17	5.0	163	2.0	8.0	2.0	3.0	185
Field pH, standard units	5.0	8.0	7.2	4.5	5.1	6.0	4.9	7.9
Specific conductance, in µS/cm	90	65	331	147	41	37	67	370
Water temperature, degrees Celsius	21.5	21.6	21.5	19.7	20.7	19.6	20.9	22.4
Dissolved solids (sum of constituents), mg/L	38	31	100	72	31	29	30	115
Nitrogen, ammonia, as N dissolved, mg/L	2.8	.04	.07	.02	.03	.04	.04	.45
Nitrogen, nitrite, as N, dissolved, mg/L	<.02	<.02	<.02	<.02	<.02	.02	<.02	.02
Orthophosphate phosphorus, as P, dissolved, mg/L	<.02	<.02	.02	<.02	.12	<.02	<.02	.02
Calcium, dissolved, mg/L	1.2	1.4	62	1.5	1.4	2.5	1.0	50
Magnesium, dissolved, mg/L	1.0	1.0	2.1	2.6	.8	.8	1.6	6.4
Sodium, dissolved, mg/L	8.1	7.0	8.5	19	6.9	5.4	6.4	14
Potassium, dissolved, mg/L	3.4	.5	.9	.1	.5	.3	.5	3.7
Chloride, dissolved, mg/L	8.8	11	9.5	35	8.9	12	12	12
Sulfate, dissolved, mg/L	8.9	2.5	.2	10	1.2	5.2	3.1	3.4
Fluoride, dissolved, mg/L	.2	<.1	<.1	<.1	<.1	<.1	<.1	.1
Silica, dissolved, mg/L	3.1	7.6	17	3.1	11	2.9	5.8	24
Bromide, dissolved, mg/L	.06	.04	<.02	.06	.02	.02	<.02	.06

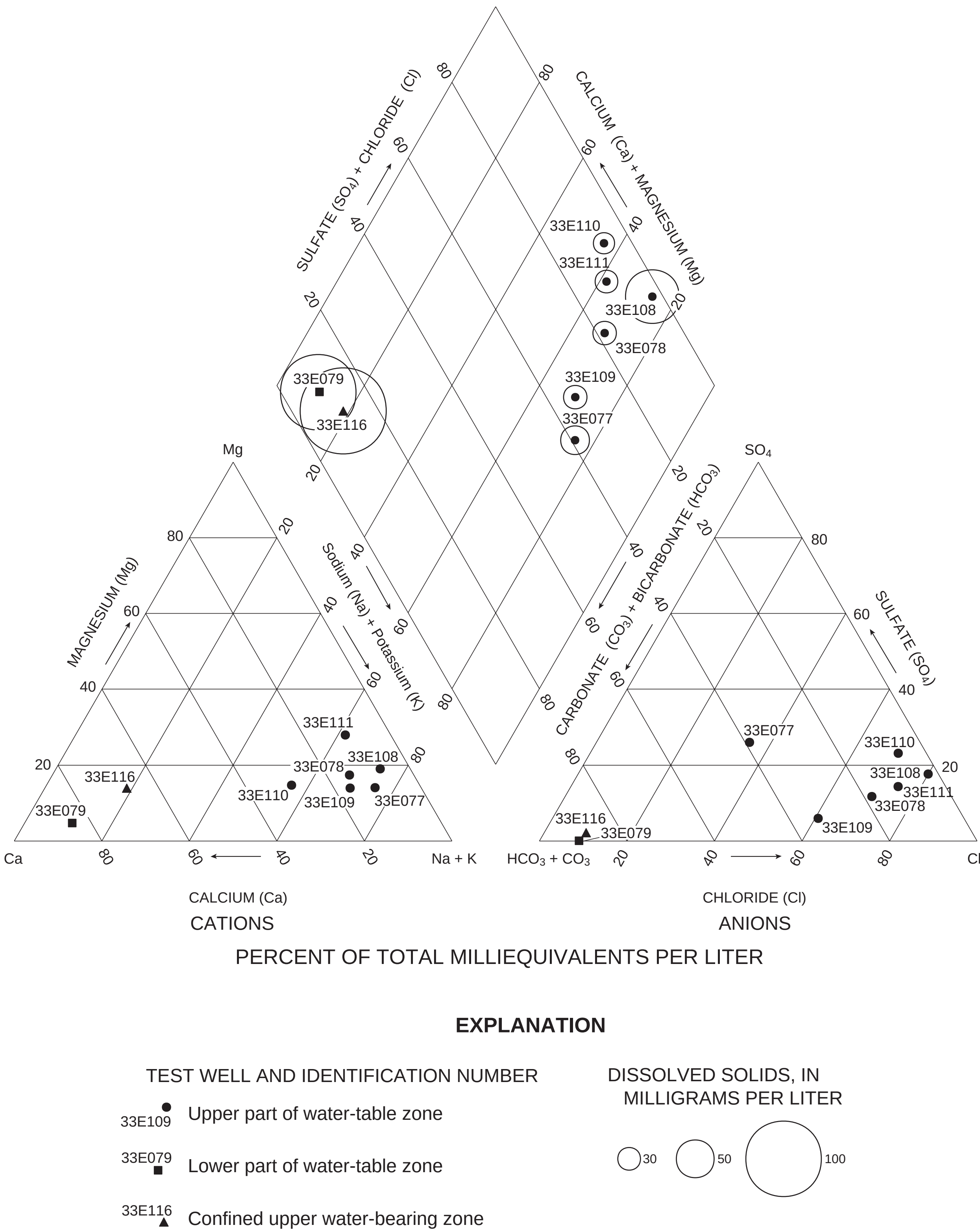


Figure 13. Percentage composition of major ionic constituents in water from selected wells at Site 11, Naval Submarine Base Kings Bay, Camden County, Georgia, April 15–16, 1997.

SUMMARY

In January 1992, volatile organic contaminants were detected in ground water at concentrations exceeding U.S. Environmental Protection Agency water-quality standards during a Resource Conservation and Recovery Act facility investigation at the former Camden County, Georgia landfill, located on U.S. Department of the Navy, Naval Submarine Base Kings Bay. The landfill, referred to as Site 11 by the Navy, was operated as a municipal landfill, and reportedly did not receive hazardous wastes. A portion of the contaminants detected have a density that is greater than water and therefore have the potential to migrate vertically in the subsurface, potentially affecting the regional aquifer system. Because of this potential, the State of Georgia, Department of Natural Resources requested that the relation of the surficial aquifer to the regional hydrogeologic framework be clearly defined. In this report, Neogene and Quaternary sediments that comprise the surficial aquifer are divided into three water-bearing zones on the basis of lithology, gamma-radiation logs, hydraulic head, aquifer-test results, and ground-water chemistry. These units, which were previously undefined, are from shallowest to deepest: (1) the water-table zone; (2) the confined upper water-bearing zone; and (3) the confined lower water-bearing zone.

The water-table zone can be conceptualized as two distinct but hydraulically interconnected zones. This zonation is apparent from differences in ground-water levels in wells completed in the upper part of the water table—above about 10 feet below sea level—compared to wells completed in the lower part of the water table—below about 40 feet below sea level. In general, ground-water flow in the upper part of the water table has a stronger horizontal component than does ground-water flow in the lower part of the water table—this preferential flow however, does not constitute confinement, but could inhibit the rate of vertical migration of compounds that are denser than water.

Water-table contours represent a subdued replica of the local topography. The water-table surface can be visualized as a water-table high or mound, partially beneath and to the east of Site 11 that slopes more steeply to the west, than in other directions. The configuration of the water-table varies over time due to seasonal variations in recharge and discharge, but the general occurrence of a water-table high beneath and to the east of the site seems to be persistent.

The confined upper water-bearing zone is hydraulically separated from the water-table zone by clay-rich sediments of the Cypresshead and Coosawhatchie Formations at about 77 feet below sea level. A single well aquifer test conducted in a well constructed in this zone, indicated that the transmissivity of this zone is about 170 feet squared per day. The confined lower water-bearing zone was not characterized in detail in this study. The occurrence of this zone is based primarily on lithologic and geophysical data. The confined upper water-bearing zone and confined lower water-bearing zone may provide a supplemental source of water supply as indicated by a test yield of 35 gallons per minute in the upper water-bearing zone and reported yields of 75 to 100 gallons per minute from drillers' acceptance tests in the lower water-bearing zone.

Estimated Darcy velocities in the water-table zone at Site 11, vary from 28 feet per year on the western side of Site 11, to 3 feet per year on the eastern side of the site. This variability is caused by variations in the water table and the value of hydraulic conductivities applied to the mathematical solution of the Darcy equation. The Darcy velocity should be used with an appropriate effective porosity to derive estimates of the average linear velocity of ground-water flow.

Water-quality analyses indicate that water in the water-table zone is chemically distinct from the confined, upper water-bearing zone and supports the conclusion of hydraulic separation between the water-table zone and the confined upper water-bearing zone at Site 11. The sodium-chloride water present in the water-table zone has a pH that is below the U.S. Environmental Protection Agency and the Georgia Environmental Protection Division secondary drinking water standards; while the calcium-bicarbonate water of the confined upper water bearing zone meets the primary and secondary drinking water standards of both the U.S. Environmental Protection Agency and the Georgia Environmental Protection Division.

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